Design of effective public transportation systems

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Abstract

The public transportation industry is facing significant problems throughout the world. Its mode share is decreasing and costs are increasing. Public transport must become more productive and attractive especially if it is to meet society's expectations for helping address environmental problems and social needs.

Productivity measures compare levels of output to inputs. Inputs include labor, capital and other goods. Effectiveness measures how efficiently these inputs are used in producing a given output. Measuring productivity or effectiveness in businesses that operate outside the market economy (like public transport) is complicated. And, without clear performance measures it is difficult to improve effectiveness. Furthermore, many public transport agencies lack the necessary tools and incentives for making efficiency improvements. These problems are exacerbated since many efficiency improvement strategies described in academic studies are not communicated effectively to practicing public transport managers.

This research develops a systematic approach for communicating public transport efficiency improvement strategies to practicing professionals. The project includes implementing an internet-based system for presenting results of technical studies in a format that encourages transport agencies to implement improvement strategies and to encourage interaction between academic researchers and practicing planners.

This paper presents interim results of an on-going research project; the author hopes this paper will spur discussion that will assist in refining all aspects of the project.

Keywords

Public Transportation – Public Transport Productivity – Public Transport Efficiency – Public Transport Speed

1. Introduction

Public transportation is expected to help play a major role in reducing energy use, air pollution, global warming and inefficient land development patterns (sprawl). However, many public transit operators are experiencing financial problems caused by rising costs and falling revenues. If these trends continue, it will be difficult for transit to effectively address these important social problems.

Over the last thirty years, government has heavily subsidized the public transport industry allowing public transport to maintain (and increase) service even as deficits have grown. Unfortunately, these subsidies have insulated public transport from the market place and have been one cause for falling productivity. Of note, the falling productivity in public transport is occurring at a time when productivity has been increasing rapidly in many other industries (even transportation-related industries). Today, however, most governments seek to reduce public transport subsidies and, therefore, agencies must become more productive.

There are many strategies that could make public transport more productive, however many of them are not being implemented to the degree they could be, and, furthermore new strategies must be developed to address current problems. In general, public transport productivity improvement strategies make public transport more efficient to operate and more attractive to customers.

There are two research related problems that may be hindering implementation of strategies for increasing public transport efficiency and productivity. First, there is not enough detailed research on individual strategies and implementation programs. Second, the available research is not organized in a format that makes it easily accessible to practicing planners. Good information is the foundation for good planning. If it is possible to quantify the benefits of a program it is more likely that an informed process can be used to determine whether to implement the program.

This project consists of developing a user-friendly[1] means of presenting research results on public transport efficiency improvement strategies. The information would be presented in a website. As the website became more popular it could serve as a means for fostering direct interaction between academic researchers and public transit agencies; these connections could

[1] In this case user-friendly is defined as in a format that makes it easy for practicing planners to obtain and use information needed to successfully implement public transportation efficiency improvement strategies.

help researchers identify especially relevant areas for further research and could also facilitate field trials of improvement strategies.

The project consists of developing a systematic approach for categorizing public transport efficiency improvement strategies, developing a consistent means of evaluating these strategies, developing an internet-based approach for communicating the strategies, and providing initial content for the website (i.e. a description of example efficiency improvement strategies). The website will be designed to allow other researchers to add research results within the categorization scheme. If the internet site proves popular, funding would be sought to expand and refine the website. The research emphasis is on developing a user-friendly way for researchers to communicate technical results to practicing public transport managers.

This research considers route level strategies rather than long-term network or agency-wide changes such as major new infrastructure improvements or new business structures. It focuses on strategies that can be used by practicing transit managers to improve operations on essentially the existing route structure to improve efficiency.[2]

Productivity is generally defined as output per unit of input. Inputs include labor, capital and intermediate goods. Productivity is often considered on an industry-wide or firm-by-firm basis, however this research focuses on productivity of specific processes (in this case elements or processes in the operation of a public transport route). Efficiency is how effective given inputs are used in producing a given output.

In the case of public transport productivity and efficiency this research focuses on reducing travel time. This measure should capture both making public transport service more efficient to operate and more attractive to customers. The idea of reducing travel times is not new, Weidmann (2005) has hypothesized that implementation of public transport efficiency improvements since World War II successfully reduced travel time in many networks making public transport more efficient and attractive (e.g. Zurich), but notes that these strategies are no longer sufficient and that travel times even in well-designed networks are starting to increase. To make public transport more efficient, productive, and attractive, travel times must be reduced.

The next chapter of this report introduces the concepts of productivity and efficiency, and then describes them within the context of the transit industry. Chapter 3 describes the proposed system for categorizing route-level public transport efficiency improvement

[2] However, comprehensive application of the recommended strategies could form the basis for major infrastructure improvements or network restructuring.

strategies. Chapter 4 describes the web-based system for presenting these strategies. Chapter 5 presents the database format and an example strategy that would be included on the website.

The author intends this paper to stimulate discussion on ways to increase the implementation of transit productivity improvement research results to practitioners. Comments and ideas are welcome on all aspects of the paper.

2. Public Transit and Productivity

2.1 Productivity

Productivity is defined as the ratio of what is produced to what is required to produce it. Usually this ratio is in the form of an average, expressing the total output of some category of goods divided by the total input of, say, labor or raw materials. (Britannica 2006)

In general terms productivity is measured as shown in equation (1). Often output is defined as the good or service produced and the sum of inputs are defined in terms of cost. This leads to productivity measures of the form: public transport agency X produced 2.5 million trips at a cost of 5 million dollars last year.

$$\text{Productivity} = \text{Output} / \sum \text{Inputs} \quad \ldots\ldots\ldots\ldots (1)$$

Efficiency is often described by normalizing productivity as the amount of inputs required to produce one unit of output. In the example it would be \$2 per trip (2.5 million trips divided by \$5 million). This value would then be compared to the cost per trip for other companies to determine how 'efficient' public transport agency X is at producing transit trips.

The objective of this research is to identify and communicate strategies that enable public transport agencies to produce more 'public transport' with fewer inputs, in other words to make public transport more efficient. Efficiency simply refers to how effective a given process is in converting inputs to outputs. For example, automobile fuel efficiency is often measured in kilometers travel per liter (or miles per gallon).

There are three types of inputs used in producing all goods and services: labor, capital and intermediate goods (equation 2). Labor is defined as the human effort that is used in the production process (often defined in hours), capital is defined as the machinery, equipment and buildings used in the production process, and intermediate goods are products purchased outside the firm used in the production process.

$$\sum \text{Inputs} = L + K + I \quad \ldots\ldots\ldots\ldots (2)$$

Where:

L = labor inputs;
K = capital inputs;
I = intermediate goods used in production;

Productivity is often defined for different inputs separately to develop a better understanding of a company's operations and compare companies. For example, company A requires 2 hours of labor to produce a widget[3], while company B requires only 1 hour of labor to produce the same widget. In this case labor productivity at company B would be higher than at company A, and managers would try to understand what caused this difference.

One reason for differing labor productivity rates at these two companies could be that company B used a higher share of capital in producing their widgets than company A. Company B may have invested (capital) in more modern machinery that allows its workers to produce one widget per hour while company A still uses the older machinery that takes two hours to produce a widget.

Equation (1) shows that there are three ways to improve productivity:

- increase output using the same inputs;
- produce the same output using fewer inputs; or
- increase output using fewer inputs.

Equation (2) shows that there are two main methods of reducing inputs – in other words making a system more efficient – one can either change the proportion of each input used in the production process by increasing the share of more efficient inputs and reducing the share of less efficient inputs, or one can improve the productivity of individual inputs.

The first method for increasing efficiency, changing the proportion of inputs used in the production process, is frequently used in public transport industry. A good example is reducing labor hours by increasing capital investments (e.g. replacing several bus lines with a single light rail line). However, this is only effective if the capital investment is more productive than the labor it replaces, which is not always true. Paaswell recommends that the productivity of capital investments in the public transit industry be carefully analyzed since "an unsound program of capital investment can lead to a 'vicious cycle' of disinvestment or overcapitalization, producing declining system reliability, rising operating costs, falling ridership and revenues, and loss of any impetus to regional economic health." (Paaswell (2005) page 13)

[3] Widgets are the term used by economists to describe a general product. In the case of public transport this could be a passenger trip or vehicle trip.

There are many examples of public transport capital investments that have failed to reduce labor costs and/or increase ridership (i.e. increase output) enough to improve overall public transport agency productivity and thus were not beneficial in the economic sense. Public transport agencies need to track costs and performance more systematically, so that they have the raw data they need to better evaluate the effectiveness of potential capital investments. This recommendation is especially true for large capital investments such as new rail transit lines and many authors have described techniques for improving forecasting and estimates (reference here).

The second method for increasing efficiency, improving the productivity of given inputs, is also used in the public transport industry. A good example is increasing the labor productivity (reducing the amount of labor needed to produce a given output) by designing bus routes so that the same operator could make three trips in an hour rather than two. Note that this would also improve capital productivity since a single bus could be used for three (rather than two) trips. Of course another way to improve labor productivity (from an economic standpoint, in other words measuring labor in terms of financial cost) would be to reduce wages.

This research is focused on short-term and relatively inexpensive changes to public transport routes and therefore considers only a subset of improvement strategies based the second method for improving efficiency. The research does not consider long-term strategies such as making major capital investments (first method) or changing an agency's organizational structure (e.g. renegotiating labor contracts, privatization). The research objective is to identify efficiency improvement strategies that can be implemented regardless of agency organization or long-term capital plans.

2.2 Productivity in the Public Transit Industry

In the theoretical sense productivity is easy to understand and measure, but in practice these are more difficult. In the private sector productivity can be measured in financial terms, which is possible since the inputs are purchased (for a price) and all the outputs are sold (again for a price). For industries that provide social goods and/or which operate outside the market system, such as public transport, it is more difficult to use financial terms to describe the output.

Meyer (1979) describes several problems in the measurement of transit productivity including, how can the special "outputs" of public transit (e.g. reduction in air pollution, provision of mobility to those unable to drive, etc.) be properly valued? And, how can the improved quality of transit service be valued? Meyer lists some of the measures suggested for measuring public transport outputs including: revenue passengers carried, revenue passenger-miles, maintenance of some minimum network and schedule, vehicle miles, and vehicle hours.

Lave (1991) gives a detailed explanation for his choice of an output measure in evaluating productivity which helps illustrate the complexity of this subject. He chooses to use total operating cost per vehicle hour because using vehicle miles (instead) would penalize transit agencies in cities with growing congestion; congestion would automatically reduce the number of vehicle miles and therefore reduce productivity. Importantly, his objective is to compare the performance of different transit agencies over time and therefore it is critical that the variables he uses are under the control of transit managers rather than simply being a function of the particular city. Pina (2001) also provides an extensive discussion of various input and output variables used in studies of public transit productivity.

Another aspect of selecting variables to measure productivity, hinted at in the discussion of Lave's approach, is that the best variable to measure depends on the analysis purpose. Hence, using company average data is good for comparing different companies, while using route-level variables is best for assessing route performance. It is possible to distinguish between three basic levels of productivity analysis in the public transport industry: agency, network design, and route. Measuring productivity at each of these levels has different objectives and therefore different variables, and choosing the most appropriate measures of productivity is problematic at all levels.

At the agency level, productivity is measured based on data related to the entire agency (e.g. all the routes, or total labor costs). In addition to the problems outlined above for evaluating productivity performance at the agency level, is the problem of public transport subsidy. Specifically, what measure does government use to determine the level of subsidy? As Pucher (1996) reports, distributing subsidies based on vehicle kilometers of service supplied (rather than passenger trips) has led some agencies to focus on service expansion instead of maximizing the usage of existing services or redistributing service toward markets with greater potential demand. The problem is compounded when provision of public transport service is privatized – selecting the correct measure for compensating the private operator is critical to program success.

Defining productivity at the level of network design is also problematic. A key question running through the public transport network design literature is identifying the best objective function that should be minimized (or maximized). In a detailed review and summary of the literature, Van Nes (1999) states that there is a fundamental problem in network design because builders (operators) want to provide the smallest possible network (to minimize production costs) while users want to have the largest possible network (to minimize travel costs/time). Both solutions are optimal from one point of view but are clearly unsuitable from the other point of view.

Ceder (1998) states that for the public transport planning process “to be cost-effective and efficient, it should embody a compromise between passenger comfort and cost of service. For example, a good match between bus supply and passenger demand occurs when transit schedules are constructed so that the observed passenger demand is accommodated, while the number of vehicles in use is minimized.” (Page 3)

The typical solution at the network design level is to express user travel time in terms of cost (in other words using an average financial value of time) and then minimize total (builder and user) costs. However, as Lee (2005) points out, “because of complex travel time characteristics, which include in-vehicle travel time, waiting time, transfer time, and transfer penalties, it has been a difficult task to optimize transit networks.” (Page 1) Furthermore, using an average figure for the value of time means that, in a perfectly functioning market, no one who valued time at a higher level than the average would use the network developed using average cost.

At the route level there are also many possible measures to use for evaluating productivity. The following section proposes using travel timesavings as a measure for evaluating the benefits of public transport efficiency improvement strategies at the route-level.

2.3 Measuring Efficiency at the Route Level

As Section 2.2 makes clear, the selection of a variable to measure efficiency is a critical part of the public transport improvement planning process. Appropriate variables must be related to the public transport agency’s organizational goals, must be impacted by the types of strategies under consideration, and should be relatively easy to measure.

At the level of transit route, a key measure of efficiency is the time it takes the vehicle to complete a trip; the less time it takes, all other things remaining equal (e.g. serves the same number of passengers, collects same amount of fares), the more efficient and productive the route. It is important to emphasize that, for the type of efficiency improvement strategies considered in this research (short term, relatively small scale), many public transport network conditions are fixed including mode, basic routing, and station structure. With the fixed network conditions, focusing on reducing public transport vehicle travel time is an appropriate objective. Without the fixed conditions reducing travel time could lead to clearly poor results. For example, travel time could be minimized by not stopping to pick-up passengers.

Reducing travel time increases average speed, one of the most important qualities for public transport. Speed improves public transport's customer attractiveness (thereby increasing revenues) and productivity (by enabling more service to be operated with the same resources). By increasing revenues and decreasing costs, speeding-up public transport provides a double benefit.

Empirical data support the thesis that public transport is more successful where vehicle speeds have been increased. Nickel (2005) reports that reducing the travel time by 21% on a series of routes in Munich (and also improving reliability) led to an increase in patronage of about 14% and an operating cost savings of about 4 million Euros. Similarly, Los Angeles' Metro Rapid Program, which placed bus rapid transit (BRT) service in several of the Los Angeles area's busiest corridors, reduced travel times by up to 29% and increased bus ridership by 20% in the Wilshire-Whittier corridor and 50% in the Ventura Blvd. Corridor. (TCRP 2005)

In addition to speed, another important aspect of public transport attractiveness is reliability. Both the Munich and Los Angeles examples described above improved service reliability and increased average speeds. Very fast service that is unreliable could be less attractive than slow but reliable service. Reliability is mostly a function of scheduling and control; if the schedule is constructed to make efficient use of the faster travel times and if controls (e.g. time-points to slow-down early vehicles, supplemental service to replace delayed vehicles, etc.) are in place to adjust to normal variations, then measures designed to speed-up public transport vehicles should not have any impact on reliability. (Although many techniques designed to improve speed do, in fact, also help improve reliability.)

Delay is also used as a measure of public transport performance. The US Federal Transit Administration report *Issues in Bus Rapid Transit* calls reducing delay the key to bus rapid transit. (FTA, ND) While there is no question that reducing delay is important, the concept of delay requires a baseline from which to measure delay; in other words it "should" take this long to complete an operation, delay is the extra time it takes. Delay has a clear meaning in evaluating travel times for a person (for example, comparing travel time on a highway with a given level of congestion to free flow conditions); but what is the comparison for public transport? This is especially critical in terms of the route level improvements that are the subject of this research. For example, one strategy for improving public transport efficiency would be to reduce the time it takes passengers to board a vehicle; measuring boarding time is a more direct way of evaluating the strategy than measuring delay (i.e. comparing actual values to some idealized value). However, clearly all techniques and improvements designed to reduce delay will also reduce travel time.

3. Efficiency Improvement Strategy Categorization

The problem of organizing information to make it accessible and useful to those who need it is growing as the amount of information explodes with modern communications and information technology. One reason public transport agencies do not implement strategies to improve public transport effectiveness may be that planners cannot find information on beneficial strategies. This chapter discusses several approaches for organizing public transport efficiency strategies and describes a proposed system in detail. *The author is especially interested in discussing ideas for organizing public transport efficiency improvement techniques into a coherent and user-friendly framework.*

3.1 Potential Categorization Schemes

There are many possible ways to organize public transport efficiency improvement strategies. The best categorization schemes will be those that are intuitive, easy to use, expandable, and meet the project objectives. Several of these qualities are closely related; for example, an intuitive scheme will be easier to use than an unintuitive one. Furthermore, these qualities are not only important when considering various categorization schemes, but are also critical when designing the information interface (in this case the website) and in determining the content provided (information on efficiency improvement strategies).

The categorization scheme should be intuitive so that users can easily find the information they are seeking. This means that the scheme should be logically organized. To a certain degree the logical-ness of any organizational scheme depends on the audience, what is logical for one person may be illogical for another. In this case the objective is to design a categorization scheme for use by practicing public transport managers and planners, but the scheme should also make it easy for researchers to add information to the database, and make the information accessible to the general public.[4]

The categorization scheme should be easy to use; otherwise it will not be used and will not serve as a useful tool for promoting implementation of public transport efficiency improvement strategies. Ease of use is widely recognized as a critical step in the development of web-based information systems, but often this consists of thinking about how best to present the information and navigate around the pages rather then thinking about how the

[4] We hope that the website information can help explain strategies for improving public transport efficiency in a manner that helps generate public support for implementing these strategies.

information might be organized or structured to make it easy to use. The best websites consider ease of use before beginning the programming process and use it as an organizational tool. The qualities that make a scheme easy to use include simplicity and intuitiveness.

The categorization scheme should be expandable so that new information can be added in a manner that maintains or improves the scheme's logicalness and ease of use. Expandability is important since we hope the database developed in this project can remain current and serve as a long-term information source for practitioners seeking to implement public transport efficiency strategies. In order to provide an expandable system that remains intuitive and easy to use, the categorization scheme should be organized with a branching structure that allows additional information to be added at more detailed levels. Thus the first level would consist of general information, the next level would be divided into logical sub-units, and further levels could branch from these sub-levels. Each level would provide more detailed data, references and tools.

Obviously the categorization scheme should be oriented to meeting the project objectives. This means that the scheme should help focus attention on the elements under control of the main audience (public transport managers and planners) and at the level (activity-arena) being considered in this study (public transport routes). In other words, the scheme should consist of logical elements that have direct relevance to the audience and activity-arena. These elements will serve as a structure for presenting information. All other qualities being equal, it is better for the categorization scheme to have a small number of elements with several sub-elements within them, than many elements that contain single sub-elements.

Table 1 presents some possible categorization schemes and qualitative ratings of their intuitiveness, ease of use, expandability and ability to meet the project objectives. Each of these schemes is described below.

Trip Process – The categorization scheme based on trip process would break-down each element of the public transport trip into a separate process and present efficiency improvement strategies for each process. Elements would include processes such as: stopping at stations and traveling between stations. This scheme would be very easy for public transport managers and planners as well as researchers to understand and use. It would be less intuitive for the general public since their focus is on their particular trip rather than the vehicle trip. The scheme would be easily expandable as it would be possible to divide it into smaller and smaller sub-processes (more detailed parts of the trip process). Since this scheme is based on the elements of the trip process it fully meets the project objectives.

Table 1 Potential Public Transport Efficiency Measure Categorization Schemes

Potential Schemes	Intuitive	Ease of Use	Expandable	Meets Project Objective	Comments
Trip Process	++	++	++	++	Categorization based on trip elements or processes (e.g. stopping at station)
Passenger Process	++	+	++	–	Categorization based on each element of the passenger's trip (e.g. travel to bus stop)
Hardware	+	++	+	–	Categorization based on physical devices or equipment used in the trip (e.g. vehicle, traffic signal)
Organizational Responsibility	–	–	+	–	Categorization based on organizational responsibilities (e.g. vehicle maintenance department, roadway administration)

Passenger Process – The categorization scheme based on the passenger process would break-down each element of the passenger trip and present efficiency improvement strategies for each of these processes. Elements would include travel to station and riding transit vehicle. Since this would be based on the passenger's trip it would be easy for the general public to understand. It would also be easy for planners and researchers to use, but it has the disadvantage of not being as useful as the trip-based scheme in supporting the project objective.

More specifically, the passenger process starts with the passenger's trip to the public transport station/stop and ends with the passenger's trip from public transport to his ultimate destination. These two elements are critical to public transport, but major changes to them are beyond the scope of this research (since passenger access and egress are part of the larger transit network design process which consists of significantly changing many routes). It should be noted that the impact on passenger stop access/egress must be considered in the improvement strategies, but, rather than being a separate element in the categorization scheme, they would be part of another element (e.g. part of the "stopping at station" element of the trip-based scheme).

Hardware – The categorization scheme based on hardware would consider improvement strategies for different physical elements of the system. Elements would include vehicle, control systems (e.g. traffic signals for road-based public transportation), and stations. This scheme would be logical for planners and researchers, but less so for the general public who are not likely to think in terms of (all) the physical elements involved in a public transport trip.

The scheme has the further disadvantage of dividing elements that might be more advantageously considered together. For example, under the trip-based scheme, the element "stopping at station" would include strategies for making this process more efficient. The strategies could be associated with many different physical elements including the vehicle or station. Considering these strategies together could help planners decide how best to meet the objective of reducing time spent stopping at stations; a hardware-based scheme might encourage planners to focus on only a single element of hardware (e.g. the vehicle) and thus miss the opportunity to achieve the objective more cost effectively.

Organizational Responsibility – The organizational responsibility-based scheme has the advantage that it organizes efficiency improvement strategies based on the public agency department that is responsible for implementing the strategies. In other words, improvements to the roadway would be organized under the roadway department. This approach has several problems. First, while this scheme makes implementation responsibilities clear, it diffuses implementation incentive. The scheme would have elements based on different agencies and departments, while some of these departments would have a strong interest in improving public transport, for others public transport may be of little interest (e.g. roadway administration). Second, since organizational responsibilities are also frequently divided along hardware lines, this scheme shares the disadvantage of limiting the scope of improvements considered. Finally, there is no standard assignment of responsibilities to departments; in other words road maintenance may be part of the public works department in one city and part of the building department in another. Thus a scheme based on organizational responsibility would not be accurate in every city.

Summary – Of the four categorization schemes considered, the trip-based scheme is intuitive, easy to use, and can be expanded easily and appears to be the best suited to meeting the needs of this project. Therefore, it will be tested in the next steps of this research project. The scheme is presented in more detail below.

3.2 Public Transport Trip-based Categorization Scheme

The typical public transport trip consists of four processes:

- Trip starting process (i.e. leaving the starting point);
- Travel between stations;
- Stops at passenger stations; and,
- Trip ending process.

Each of these processes includes several sub-processes. The processes and sub-processes can be made more efficient by implementing strategies designed to reduce travel time. The research project objective is to improve the communication of these strategies to public transport managers and planners. It proposes to achieve this objective by constructing a website using a categorization scheme based on the trip-based processes and sub-processes. These processes are outlined below.

3.2.1 Trip Starting Process

The "trip starting" process is critical to public transport operations since vehicles that do not start their routes on time generally fall further behind as they travel along their route (since they must pick-up more passengers at each stop than expected). This process is especially problematic since, as the late-starting vehicle falls further behind, the following vehicle catches-up with it (since it is picking up fewer passengers at each stop), causing vehicle bunching and significantly reducing service quality and attractiveness. The sub-processes in the trip starting process consist of:

- Operator break time – the time required before starting a new trip for the operator to take a rest. This is often a subject of labor agreements.
- Recovery time – the time between trips needed to enable a late arriving vehicle to leave the starting point on-time.
- Travel from layover time – the time it takes the transit vehicle to travel from the route layover point (the place where the operator takes a break and recovery time is spent) to the route starting point (first stop).

3.2.2 Travel Between Stations

The "travel between stations" process consists of the time public transport vehicles spend moving between stations. There are two main parts of this process. The first consists of time spent moving between stations not including the acceleration and deceleration associated with station stops. For public transport vehicles using an exclusive right-of-way, only other transit vehicles will impact travel time between stations. For public transport vehicles using a shared ROW, travel time between stations will be similar to that of other vehicles unless the public transport vehicle has some particular benefits (priority at traffic signals) or impedances (it must travel in a specific lane that is more congested than other lanes). The second main part consists of the public transport vehicle's acceleration and deceleration associated with stops at transit stations. The sub-processes in the travel between stations process consist of:

- Time in motion – this consists of the time that the public transport vehicle spends in motion between stations. It includes acceleration and deceleration not associated with traffic signals or station stops.
- Time at traffic signals – this consists of time spent braking for traffic signals, the time spent stopped at traffic signals, and the time it takes to accelerate from traffic signals to operating speed.
- Station acceleration/deceleration time – this consists of time spent decelerating to stop at a station and time spent accelerating back into the traffic stream from a station stop.

3.2.3 Stop at Passenger Stations

The "stop at passenger stations" process consists of the time spent by the public transport vehicle at a station. It consists of the following sub-processes:

- Door opening time – this consists of the time spent between stopping the vehicle and when the doors are completely open.
- Alighting time – this consists of the time it takes for passengers to alight the vehicle.
- Boarding time – this consists of the time it takes for passengers to board the vehicle.
- Door closing time – this consists of the time between when the doors start to close and when the vehicle can begin moving.
- Return to traffic time – this consists of the time it takes the vehicle to return to the travel lane from the bus stop.

A route's total stop at stations time is equal to the sum of stop at station times for all stations.

3.2.4 Trip Ending Process

The "trip ending process" completes the cycle and consists of:

- Travel to layover time – the time it takes the transit vehicle to travel from the route end point (last stop) to the layover point.

The cycle then begins again with the trip starting process.

4. Public Transportation Efficiency Project Database

The project objective is to encourage the implementation of public transport efficiency improvement strategies at the route level. The approach selected to obtain this objective is to better communicate results of academic and practical studies to practicing public transport managers and planners by developing a database of efficiency strategies and publishing this database on the internet. This chapter outlines a proposed organizational structure for the project's internet site.

4.1 Database Users

The database will have three types of users: public transport managers and planners, researchers, and interested members of the public.

Researchers will be able to use the website database to publicize the results of their research to practicing public transport managers and planners. This will help assist in the dissemination of academic results into practice increasing the relevance of research. It could also help researchers develop relationships with public transport planners who could assist in research projects by providing data and potential field testing. Researchers would be able to add information to the database on research they have completed.

Public transport managers and planners will be able to use the website database to easily obtain information about various strategies for improving the efficiency and attractiveness of their public transport systems. They will also be able to contact researchers to obtain more information on relevant studies and strategies. Public transportation planners would be able to add information to the database on strategies they have implemented.

Interested members of the public will be able to use the website database to learn about strategies for making public transport more efficient and attractive. The assumption is that if the public understands the importance of efficiency improvement strategies (and how they work), they will be more inclined to support strategy implementation. Having this type of information available to the public will also help reduce the amount of time public agency planners need to spend explaining improvement strategies to interested individuals (they will be able to refer people to the website). The public would not be able to add information to the database without special permission.

4.2 Database Information

Chapter 5 describes the database information in detail. Essentially the database would describe public transport efficiency improvement strategies at various levels of detail and would provide references for more detailed information. The information would be presented using the trip-based scheme outlined in Chapter 3. There would be a separate webpage with links to other pages and references for each efficiency improvement strategy.

4.3 Proposed Website Structure

In terms of website structure there will be two main groups of website users: the interested public and researchers/planners. The public will be seeking general information while the researchers/planners will be seeking more detailed information.

The top level of the website would present general information about public transport efficiency including why it is important, the benefits of efficiency improvement programs and summary descriptions of the strategies organized using the trip-based scheme (Chapter 3), users could click on a link to get more detailed information. This page would also include general information about the website and research project.

The second level of the website would present more detailed information about the research project and improvement strategies. The page would include tables for each of the trip processes. Each table would include a row for each sub-process and links to specific improvement strategies designed to reduce travel time for that particular sub-process.

The third level of the website would describe specific public transport efficiency improvement strategies. The pages would include a concise summary of the strategy, a more detailed description of the strategy, and information on research (see Chapter 5 for a detailed description of the information and format for data on this page).

4.4 Database Input and Maintenance Process

The project consists of developing an initial website, providing initial content for the site and limited publicity. If the effort proves interesting to the research and planning community (based on outside use of the site), we would seek to find a sponsor to maintain and expand the site. The following process would be used to maintain and expand the site:

- The first and second levels of the website would be completed by and maintained by the site administrator.

- The third level of the website would be prepared and maintained by the site administrator, but data would be added and edited by researchers. This page would include two types of input methods: a form-based database entry form (researchers would use this form to enter data about their research project) and a WIKI-based research description section. The WIKI format allows users to add text, images, and links and allows them to edit the existing contents of the site. There are many WIKI programs available and WIKIs are becoming a popular way for presenting and organizing information on the Internet.

- Researchers and planners would be allowed to add data about their research projects to the website. They would need to get permission from the site administrator, which would be granted based on receipt of an e-mail describing the researcher's/planner's field of research and contact information. Once a researcher/planner was registered they could add information to the site or edit the site at any time.

- The site administrator would control access to the site and be responsible for general maintenance of the website.

- The site's technical advisor would be responsible for periodically reviewing the site's content to ensure that it was appropriate and met high-level technical and written quality standards. Depending on the level of interest and resources available, the technical advisor could also serve as a defacto editor, re-writing and/or consolidating information on the site to make it more clear and useful. Eventually there could be several technical advisors each responsible for a specific section of the site.

5. Public Transport Efficiency Improvement Strategies

This chapter presents examples of public transport efficiency improvement strategies of the type that would be included in the internet site database prepared as part of this project. The intention is to provide the reader with an idea of the type of information that would be provided and the proposed format. The project objective is to provide a format and structure for the database, enter initial content into this structure, and encourage other researchers and practitioners to add more techniques to the database.

5.1 Efficiency Improvement Strategy Format

In order to make the proposed database easy to use it should have a consistent format. The database is not intended to include all the information about a particular strategy, but it should include the following information:

- Concise strategy description;
- Detailed strategy description; and
- Research projects – which consists of:
    - Research summary table;
    - Planning and analysis tools table; and
    - Research projects description.

Note that this format consists of two different types of information. The first type of information describes the efficiency improvement strategies in general terms and is presented in the concise description and detailed description. The second type of information describes particular research studies related to the efficiency improvement strategies. These research studies should provide findings that help support implementation of the particular efficiency improvement strategy. Each element of the basic format is described in more detail below.

In the descriptions below, the term research is being used to mean both academic research and results from project implementation studies (e.g. before and after studies) completed by public transport agencies themselves. Similarly, the term "researcher" is used to mean either an academic or person responsible for implementing a particular project at a public transport agency (e.g. project planner, manager, etc.).

In general researchers would enter data regarding their research using a form-based system to ensure consistency and to allow placement of information in the proper website locations. In the case of the detailed strategy description, researchers would add and/or edit information using a WIKI format. Each section of the website and specific requirements are outlined below.

5.1.1 Concise strategy description

The concise description consists of a short description of the public transport efficiency improvement strategy written in a style that can be understood by both professionals and interested members of the general public (in other words people who have a basic understanding of public transport operations).

5.1.2 Detailed strategy description

The detailed description section describes the public transport efficiency improvement strategy for professional and academic audiences. It should describe the strategy, its application, and its effectiveness in detail. Effectiveness should be presented in terms of travel time savings to the degree possible. The detailed description section should provide enough information to enable a public transport agency planner to fully understand the strategy and help her determine if it is applicable to the problem she is trying to solve.

The detailed description would be designed to allow researchers to edit and/or add to the section (using a WIKI format) based on the results of their studies. Researchers could add several sentences about their research and edit the existing text to provide an overview of the research field and how their particular research fits within this context. This summary would be similar to a written paper’s literature review although it would be constantly updated as each new research study was added to the database.

5.1.3 Research projects

The research projects section describes research projects completed on specific techniques designed to implement the public transport efficiency improvement strategy. The section will summarize research projects and describe each research project in detail. The section includes the three sub-sections: research study summary table, planning and analysis tools table, and research project description.

Research Project Summary Table – The research project summary table will summarize research study findings. It would be presented in a tabular format to allow site visitors to quickly gauge the importance of various improvement measures. Researchers would provide summary information on their research projects on a data entry form. The website would then display this information as a new row of data in the summary table. The data would include study name, very short description, measure(s) of effectiveness, results, author contact information, and a study citation (with link to view full study report, if possible).

Planning and Analysis Tools Table – This table would list any simulation or analysis tools that were developed as part of the research project. It would also be presented in tabular format with each row describing a specific tool. The data would include the analysis tool's name, a brief description of what the tool can be used for, and information on obtaining the tool. Researchers would enter this information on the study entry form.

Research Project Description – This section of the website would describe the research projects in detail. The information provided for each study would be analogous to a well-written set of conclusions for a published paper. It would summarize the research project problem, hypothesis, experiment, results, and recommendations. This section would be linked with a hyperlink to the Research Project Summary Table so that site visitors could use the contact and/or citation information in the table to contact the authors or download the study.

5.2 Example Strategies

This section presents an example of the website's content for a specific public transport efficiency improvement strategy. The example is in text format and includes written descriptions of internet-related page elements. Text in parentheses describes the type of content in terms of the format described above.

The example describes optimal public transport stop spacing.

5.2.1 Concise Description

Public Transport Station/Stop Spacing

The spacing between public transport stations (stops) must be carefully considered to balance the need for passenger access and transit vehicle speed.

The more often a public transport vehicle must stop the slower its average speed. Slower speed means less attractive service to passengers and increases the cost of providing service. On the other hand, transit vehicles must stop to pick-up and drop-off passengers so stops cannot be totally eliminated. The key is to balance the need for passenger access to public transit stops with the benefits of increasing transit vehicle speed.

5.2.2 Detailed Description

Research supports the conclusion that station spacing for most public transport systems is too short (i.e. stations/stops are too close together). Ideal spacing of 600 – 700 meters for bus stops and about 800 meters for tram lines appears to be appropriate.

(Text here would discuss research on this subject in a WIKI format)

5.2.3 Research Projects

Research Projects Summary Table

Table 2 Public Transport Station Spacing Research Results Summary

Research Study	Performance Measure	Findings	Comments
VanNes (2000) *(link)*	Stop Spacing	Spacing generally too close; optimal spacing 600-700 meters (bus) and 800 meters (tram).	Spacing values are approximate and should be based on specific conditions. Research describes methodology in detail.
TCRP 26 (1997)	Bus Trip Time	Buses spend 9-26% of time at passenger stops.	Data is from US (1982). Report describes effectiveness of many techniques for speeding up buses on arterials.
Another Study (date) *(link)*	xxx	xxx	xxx

Planning and Analysis Tools Table

Table 3 Public Transport Station Spacing: Planning Tools

Research Study	Planning Tool Type	Uses	Comments
Study1 (date) *(link)*	Computer Program	Estimates optimal bus stop spacing.	Program can be used with GIS population data to balance passenger access time and transit vehicle travel time. Contact: xxx@yyy.
Study2 (date) *(link))*	Spreadsheet	Estimates optimal bus stop spacing.	Users enter population and simple geographic data into spreadsheet which calculates passenger time and agency costs to analyze sensitivity of different stop locations. Contact zzz@bbb.

Research Projects Description

(Research Study 1)

Van Nes 2000 – Van Nes completed a research study on the question of optimal stop and line spacing for public transportation networks including a substantial review of the literature (van Nes, Rob; *Optimal stop and line spacing for urban public transport networks, Analysis of objectives and implications for planning practice*; TRAIL Studies in Transportation Science No. S2000/01; Delft University Press, Delft; 2000; www.TRAIL.tudelft.nl).

The study describes the problem background and analytical techniques used in optimizing passenger access time and transport agency costs (with various objective functions). It also considers how bicycle access to stations could reduce passenger access time and what impact this has on stop and line spacing. The study summary (page v) concludes:

Based on the research study "clear recommendations for planning practice emerge. Current network design focuses too much on short trips and on access distance only, while ignoring in-vehicle time, waiting time, and operational costs. As a result, existing urban public transport networks are too expensive. Opting for a balance between traveler costs and operator costs and focusing on longer trip lengths, will result in twice the traditional stop spacing for bus and tram networks, and in twice the traditional line spacing for bus networks. Implementing these changes will lead to a significant reduction of operational costs, while service quality is maintained or improved and thus ridership is maintained or increased. Improving cycling facilities at and around stops will further enhance these favourable shifts."

(Research Study 2)

TCRP Project 26 (Operational Analysis of Bus Lanes on Arterials) – This report summarizes many research projects on various strategies for improving the speed of buses. Of particular interest is information it reports on the share of time typical buses spend on various elements of its trip. It states that the typical bus spends about 48-75% of its time moving, 9-26% at passenger stops, and 12-26% in traffic delays. Cars are consistently 1.4 to 1.6 times faster than buses. (This information was reported by: Levinson, H. S. INET Transit Travel Time Analysis. Prepared for UMTA, U.S. Department of Transportation, 1982; and, Levinson, H. S. Analyzing Transit Travel Time Performance. In Transportation Research Record 915, TRB, National Research Council, Washington, DC, 1983.) The information is from US sources and was collected in 1982. The significant variability of the data, a difference of 17% for time spent at passenger stops shows that the stop time can vary substantially and therefore bears investigation. The variability also suggests that completing a simple study comprising of collecting these times for routes could provide valuable information for improving productivity (it would show the most worthwhile areas to focus on).

(Additional research studies.)

Study XYZ – More studies would be presented here.

5.3 Website: Beta Version

A beta version of a website based on this structure has been developed and can be viewed at: www.andynash.com/pte-project/pte-home.html

The author welcomes comments on all aspects of the project, especially on the structure of the information and the project's overall objectives.

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